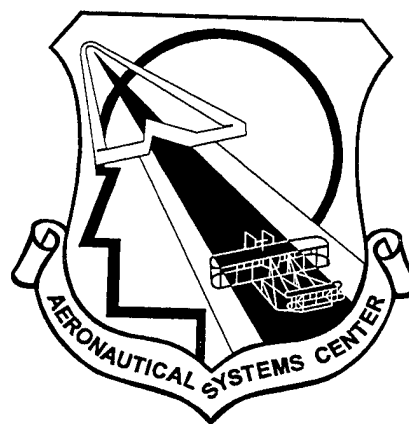


ASC-TR-1999-5004



**AN EVALUATION OF DATA
ENTRY DEVICES**

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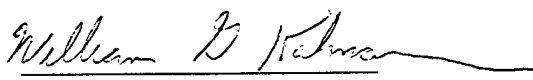
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EXECUTIVE SUMMARY

Current Air Force direction calls for the installation of Global Positioning System (GPS) equipment in the T-38 prior to FY2001. Integration of GPS on the aircraft will require the installation of a GPS antennae, avionics "boxes," and a control display unit (CDU). Guidelines from the USAF GPS Integration Guidelines (GIG) call for the use of alphabetic identifiers to define waypoints. With this requirement the question arose as to whether or not a full alphabetic keypad for data entry was required when integrating GPS into aircraft. Past evaluations have compared full alphanumeric keypads to partial keypads, but none have compared alternate types of entry such as knobs or "increase/decrease" buttons. As part of this study, the Crew Station Evaluation Facility (CSEF) evaluated 6 different implementations of alpha character data entry for time to enter data, accuracy, and attention required.

The primary objective of this evaluation was to assess subject performance using various techniques for alphanumeric data entry. To accomplish this objective, the performance of 13 subjects was compared across 6 data entry devices and 6 data types. Subjects performed a simple tracking task while simultaneously entering alphanumeric data. Performance data were collected for the tracking and data entry tasks, and subjective data were collected from the questionnaires.

The data entry devices were: 1) Full alphanumeric keypad, 2) "Telephone" type keypad, 3) Dual knob, 4) Single knob, 5) Rocker switch, and 6) An International Civil Aviation Organization (ICAO) database table.

The 6 data types were: 1) 3-letter alpha character identifiers, 2) 4-letter alpha character identifiers, 3) 5-letter alpha character identifiers, 4) 3-letter alpha character identifiers combined with 5-digit Radial/Distance Measurement Equipment (DME) numeric, 5) Latitude and Longitude coordinates, including N, S, E, and W for the hemisphere, and 6) UHF Radio Frequencies.

Overall, the subjective as well as the objective results indicated the most preferred device and best performance were obtained with the full alphanumeric keypad. The ICAO table was second place in preference and performance.

The Analysis of Variance of the Subjective Workload Dominance (SWORD) data was not significant suggesting that there was no workload effect across the 6 data devices.

The data conclusively indicated that the full alphanumeric keypad was best, but if space is a limitation, the ICAO table with a numeric keypad is acceptable. The dual knob and telephone keypad devices should be avoided.

1. INTRODUCTION

Current Air Force direction calls for the installation of GPS Equipment in the T-38 prior to FY2001. Integration of GPS on the aircraft will require the installation of GPS antennae, avionics "boxes," and a CDU. A CDU is a piece of hardware normally consisting of an alphanumeric keypad, function keys, and a display. It functions as both a control panel and as an information display for various systems.

The Subsystems SPO (ASC/SM) had the responsibility for the acquisition of a CDU for the T-38. Prior to pursuing a formal acquisition effort, the Subsystems SPO tasked the CSEF to assess the benefits provided by various CDU options and to assess CDU functional requirements for the T-38. The CSEF evaluation focused on CDU location in the cockpit and functionality, and how these affect the pilot acceptability of the system. The results of this evaluation are discussed in CSEF-TR-94-0001. It was CSEF's initial work with the CDU that prompted the need for accomplishing the current data entry study.

Guidelines from the USAF GPS GIG call for the use of alphabetic identifiers to define waypoints. With this requirement, the question arose as to whether or not a full alphabetic keypad for data entry was required when integrating GPS into aircraft. Currently, there are many CDUs available which utilize full alphabetic keypads to allow aircrews to accomplish this task. In addition, there are some CDUs which utilize a "telephone" keypad approach. So far, no known Up-Front Control (UFC) panels provide for alphabetic character entry. Commercial systems also utilize various other techniques of character entry, including knobs and buttons to "increase" or "decrease" the value of a character. Past evaluations have compared full alphanumeric keypads to partial keypads, but none have compared alternate types of entry such as knobs or "increase/decrease" buttons. The CSEF study evaluated 6 different implementations of alpha character data entry for time to enter data, accuracy, and attention required. This report describes the approach for conducting this evaluation.

1.1 Test Objective

The primary objective of this evaluation was to assess subject performance using various techniques for alphanumeric data entry. To accomplish this objective, subject performance was compared across 6 data entry devices and 6 data types. The data entry devices compared were: 1) Full alphanumeric keypad, 2) "Telephone" type keypad (3 letters on each numbered button), 3) Dual knob - one knob cycled through all alpha characters and one knob cycled through all numeric characters, 4) A single knob which cycled through all waypoints identified by alpha characters in the database and a keypad used for numeric character entry, 5) A rocker switch used to "increase" or "decrease" the value of the alpha character and a keypad for numeric character entry, and 6) ICAO database table listing all alpha codes and a numeric keypad for numeric entry. Reference Appendix A for a detailed description of the operation of each data device.

The 6 data types were: 1) 3-letter alpha character identifiers, 2) 4-letter alpha character identifiers, 3) 5-letter alpha character identifiers, 4) 3 letter alpha character identifiers combined with a 5 digit Radial/ DME numeric, 5) Latitude and Longitude coordinates, including N, S, E, and W for the hemisphere, and 6) UHF Radio Frequencies (see Table 1).

TABLE 1. DATA TYPES

DATA TYPE	SAMPLE
3-LETTER CODE	SHV
4-LETTER CODE	KDYS
5-LETTER CODE	OVETO
LATITUDE	N36 39.80
LONGITUDE	W121 36.11
RADIO FREQUENCY	362.2

2. METHOD

2.1 Subjects

Thirteen subjects representing a mix of rated, non-rated, males, and females participated in the evaluation. The average age was 36 years with a range from 24 to 48 years. Of the 6 rated subjects, 2 were banked pilots, 1 was a tanker pilot and 3 were private licensed pilots. All subjects tested all data entry devices. Reference Table 2 for subject background data.

TABLE 2. SUBJECTS'S BACKGROUND DATA

SUBJECT NUMBER	AGE	RATING	AIRCRAFT FLOWN	TOTAL FLYING HRS
2	33	NR+		
3	29	NR		
4	28	BANKED PILOT	T- 37, T-38	280
5	29	PILOT	T-37, T-38, C-135KC-135	1800
6	24	NR+		
7	39	NR		
8	25	BANKED PILOT	T-37, T-38	195
9	45	NR		
10	32	NR+		
11	46	NR		
12	48	NR		
13	43	NR		
14	48	NR		
AVERAGE	36.07			

Subject 1 was dropped from the analysis.

NR - Non-rated
+ - Private Pilot

2.2 APPARATUS

2.2.1 Crew Station Evaluation Facility (CSEF)

The Crew Station Evaluation Facility (CSEF) is an Air Force simulation facility that is operated and managed by the Crew Systems Branch (ENFC) of the Aeronautical System Center's Flight Systems Engineering Division (ASC/ENF) at Wright-Patterson AFB. The facility supports the System Program Offices in their acquisition engineering through crew interface evaluations using human-in-the-loop simulation. Currently, the CSEF has the capability to perform full and part mission simulations for a variety of aircraft including the B-1, F-16, KC-135, F-22 and T-38.

2.2.2 Aggressor Station

For the study, the CSEF "Aggressor Station," a single seat cockpit simulator was used. The aggressor station consisted of a cockpit shell with an ACES II ejection seat, an F-16 style side mounted control stick, simulated throttles, and an intercom headset. A black foamcore instrument panel housed two Sony 8-inch color monitors mounted side-by-side in the front instrument panel area. For this study, only the left monitor was used. The data entry devices were located in the center pedestal. A quick disconnect was used so the data devices could be easily and quickly removed. The lower edge of the center pedestal mounting bracket which housed the data devices was approximately 15-inches above the simulator's floor. The ejection seat was mounted at an angle such that height adjustment also proportionately moved the seat closer or farther from the instrument panel to accommodate leg length. In order to separate the subject from the experimenter during data collection, the aggressor station was enclosed by 8-foot-high partitions.

2.2.3 Control Display Units

There were 6 different data entry devices. Three of the units used a Collins CDU, Model CCD-840-5A, either as manufactured or in modified form, and 3 of the units were built in-house (see Appendix B). Each device incorporated a different technique for alphanumeric data entry. All devices had the following shared characteristics: 1) Each device consisted of a control panel and a small Cathode Ray Tube (CRT) display located directly above the control panel; 2) Once all the characters for an entry had been made, pressing the "Line Select Key" finalized the entry; and 3) Each device utilized a "Clear" key which erased the last character to appear on the first press, erased the next character to the left on the second press and so-on until the entire line was clear.

The CRT for the Collins CDU provided 22 characters horizontally and 5 lines vertically. For the other 3 units, the CRT provided 22 characters horizontally and 3 lines vertically.

There were 2 CRT formats: 1) A scratchpad format which was only used on the full alphanumeric data device and 2) A field format which was used with all the other devices. In the scratchpad format, a display line at the bottom of the CRT temporarily displayed the characters as they were entered. Once the subject was satisfied with the entry, pressing the appropriate Line Select Key (LSK) moved the entry to the appropriate LSK field and finalized the entry (see Figure 1). In the field format, the subject selected the appropriate LSK prior to entering the data. The data entry occurred in the field next to the LSK, and final acceptance of the data was made by pressing the LSK a second time (see Figure 2). A template was used for all the parameters with both formats so the subject did not enter periods, slashes or degree symbols. Also, the location of the different data types on the CRT was always the same regardless of data device.

2.2.4 Experimenter's Console

The experimenter's console included an IRIS Silicon Graphics 15-inch color monitor, keyboard and mouse, an IRIS Indigo computer and an intercom headset. The IRIS Indigo computer was used to record and automate voice commands for cueing subjects as to when and what data to enter during the practice and test trials. From the console, the test engineer controlled the simulator operation and selected test parameters (test subject number, test conditions, test session, etc.).

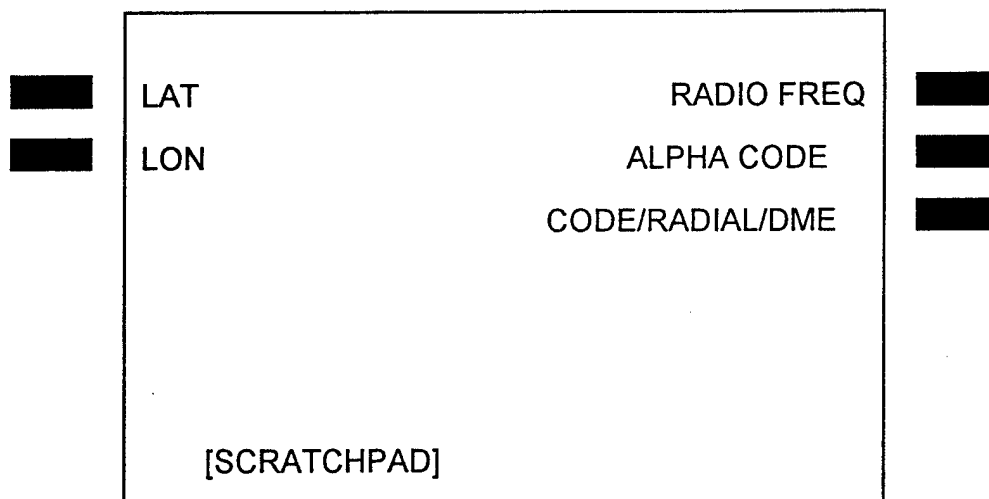


FIGURE 1. CRT SCRATCHPAD FORMAT

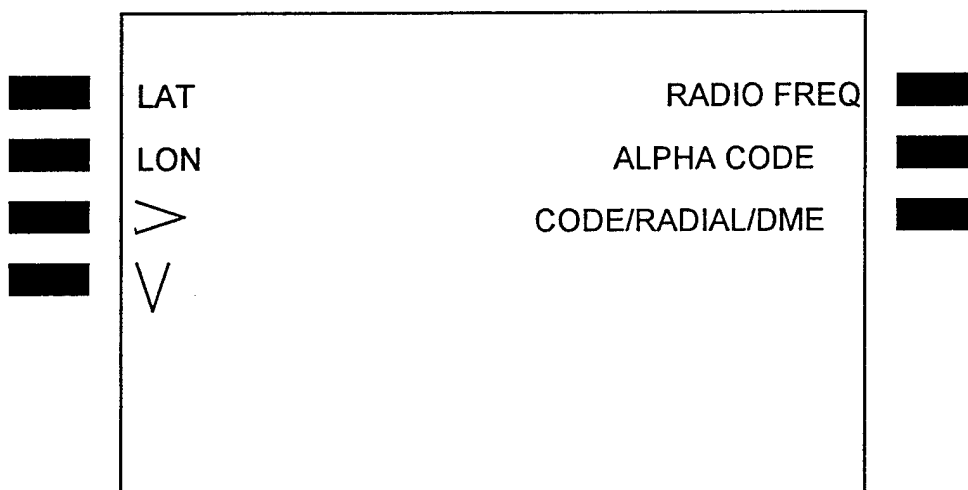


FIGURE 2. CRT FIELD FORMAT

The right and down LSK arrows were only visible and used with the ICAO Table configuration.

2.3 Tasks

There were 2 tasks: 1) a simple tracking task, and 2) the data entry task. The tracking task consisted of a set of crosshairs and a moving box. The subject's task using his/her right hand was to keep the crosshairs centered on the moving box by using the side stick controller. The crosshairs were representative of a missile sensor system and the system directional control was modeled after an aircraft flight director system.

The second task, the data entry task, involved inputting the 6 different data types using the left hand while simultaneously performing the tracking task with the right hand. Tracking performance and data entry performance data were collected.

2.4 Materials

Subjects used a pilot's kneeboard on their right knee to hold a listing of the data items to be entered during practice and test sessions. A list of 24 data items (1 list for practice and 1 list for testing) was used (see Table 3).

TABLE 3. TEST DATA ITEMS

1. BZA	13. CZQ 86/27
2. FLG 247/65	14. 253.5
3. 295.7	15. FQF
4. N36 39.80 W121 36.11	16. TLAGO
5. KFAT	17. S70 36.91 E120 45.83
6. VINTA	18. ZUN 251/67
7. 384.9	19. KHMN
8. GBN 247/66	20. N33 42.43 W082 09.79
9. SHV	21. FRACA
10. KDYS	22. KSZL
11. S85 63.12 E156 32.47	23. OVETO
12. TXK	24. 362.2

2.5 Procedure

Subjects were given a background briefing to familiarize them with the purpose of the study and the tasks to be accomplished. After the initial briefing, they were familiarized with the simulator and given a practice session with the tracking task. Once the subjects were comfortable with the tracking task, they were given a coached practice session using the device to be tested. Subjects were allowed to practice until they were comfortable with the test device but a minimum of 5 practice trials were required.

Once the practice session was concluded, the test session began lasting 10 to 25 minutes depending upon the particular data device and the personal speed of the test subject. At the end of the test session, the subject disembarked the simulator and completed a short questionnaire on the test device.

A 15-minute break allowed the subject to rest between test sessions and provided for the next testing device to be installed. The subject would again have a coached practice session on the new data device and then

start the next test session. This procedure was repeated until all 6 data devices had been tested. At the end of the test session, the subjects completed a Subjective Workload Dominance (SWORD) Assessment and a background and overall questionnaire. Total testing time varied per subject but averaged 3 1/2 to 4 hours.

In a typical session the subject began the tracking task, then via the intercom headphones an automated voice announced the number of the data item the subject was to enter. The subject referenced the list strapped to his/her knee and entered the data. On the CRT in the lower left-hand corner, the same number appeared as the voice command providing a visual reference in case the subject misunderstood the audio command or wanted to confirm the item number. Once the subject made the final acceptance of that data item, the data item number on the CRT changed to zero. Voice commands were given approximately every 10 seconds.

The testing order of the data devices was counter balanced across subjects using the testing order per Table 4. The order of the test data items was randomized by a computer for each session.

TABLE 4. TESTING ORDER FOR DATA DEVICES

SUBJECTS	DEVICES	A	B	C	D	E	F
	7, 13	1	2	3	4	5	6
	2, 8, 14	2	4	3	6	1	5
	3, 9	3	1	2	5	6	4
	4, 10	4	6	5	2	1	3
	5, 11	5	1	6	3	4	2
	6, 12	6	5	4	3	2	1

Legend: A - Rocker Switch
 B - ICAO Table
 C - Single Knob
 D - Full Alphanumeric
 E - Telephone Keypad
 F - Dual Knob

2.6. Data Collection

2.6.1 Objective Data

Measures of Performance - Performance measures were collected for: 1) Time from end of message to first input on the data entry device, 2) Time from initial character entry until the enter key was pressed, 3) Root Mean Square (RMS) data for variation from heading, altitude and airspeed, 4) Number of uncorrected errors per trial, 5) Number of corrected errors per trial, and 6) Number of incomplete input errors per trial.

2.6.2 Subjective Data

Measures of Workload - SWORD Technique. The SWORD technique uses a series of relative judgments comparing the workload of various tasks. In this case, the subjects compared the 6 data devices. Each subject made 15 relative comparisons (see Appendix C).

Questionnaire Data. Subjects completed a questionnaire asking background data and qualitative assessment of the CRT format, the data devices and any comments on the study (see Appendices D and E).

2.7 Experimental design

The experimental design was a 6 x 6 rank order analysis for dependent samples (repeated measures). The independent variables were data entry device type (6) and data type (6). The dependent variables were reaction time (time from end of audio message to first action of data entry), time to enter data (total time of data entry), RMS error data for tracking task (during data entry), number of uncorrected errors per trial, number of corrected errors per trial, and number of incomplete input errors per trial.

The workload analysis was a one way Analysis of Variance (ANOVA). Rank order analysis was used for the subjective questionnaire data.

3. RESULTS

There were 8 subjective and 13 objective indices analyzed using rank order non-parametric statistics. Rank order analysis was used since the subjective data was ordinal in nature and no assumptions could be made about its statistical distribution. The objective data was transformed to rank data for comparison purposes with the subjective data.

Data were analyzed for overall subjects, pilot and non-pilot effects to determine if pilots subjective and objective data differed from non-pilots. There were no significant differences ($p > .05$) between overall, pilots and non-pilots on any of the subjective or objective measures (Chi-squares ranging from .01 to 1.35, adjusted for ties). Therefore, this report will only address overall pilot results.

3.1 Subjective Results

The subject data were looked at for mean scores for all the subjective measures.

Table 5. Mean Values for Devices — Subjective Measures

DEVICE	Perceived difficulty	Locating desired key	Entering alpha character	Entering numeric character	Entering alpha numeric combination	Probability of committing an error	Detecting an error	Correcting an error
Full keypad	4.19	3.38	3.62	4.38	3.77	2.92	3.46	3.92
Telepad	3.04	3.15	2.62	4.15	3.08	2.92	3.46	3.23
Dual knob	3.23	4	3	3.38	2.85	2.92	3.23	3.38
Single knob	3.69	3.46	3.54	4.23	3.15	2.46	3.46	3.31
Rocker switch	3.35	3.69	2.69	4.38	3.54	2.85	3.31	3.69
ICAO table	3.85	4	3.69	4.54	3.54	2.46	3.54	4

For Table 5, the higher the mean rating for all the categories the better, except for the "probability of error" question. For that question, a lower numeric rating is a favorable response since the subjects are indicating that they are less likely to make an error using that data device. In all other questions, the higher the rating the better (maximum score possible was 5).

In terms of perceived difficulty, the full alphanumeric keypad was rated the most favorably, closely followed by the ICAO table. The telephone keypad was perceived as the most difficult device to use.

An average rank was computed for each device for the subjective measures as shown in Table 6. The rankings were computed based on the average mean scores across subjects and then ordered based on the rankings of the 6 devices for each participant; a rank of 6 was best.

Table 6. Average Ranks for Devices — Subjective Measures

DEVICE	Perceived difficulty	Locating desired key	Entering alpha character	Entering numeric character	Entering an alphanumeric combination	Detecting an error	Correcting an error	Overall Mean Rank by Device *
Full keypad	5.15	3.04	4.46	3.96	4.54	3.69	4.35	4.17
Telepad	2.31	2.58	2.31	3.27	3.08	3.62	2.58	2.82
Dual knob	2.62	4.15	3.08	1.69	2.42	3.12	3.15	2.89
Single knob	3.73	3.27	4.15	3.77	3.04	3.62	2.88	3.49
Rocker switch	2.73	3.65	2.31	3.92	3.96	3.27	3.58	3.34
ICAO table	4.46	4.31	4.69	4.38	3.96	3.69	4.46	4.28

* Mean calculation excludes error probability

For the subjective measures as a whole, the full alphanumeric keypad and the ICAO table were ranked the highest (4.17 and 4.28, respectively from a possible 6).

The Friedman Analysis of Variance by Ranks (a non-parametric analog of the 2-way ANOVA) was completed for the data in Table 6. There was a significant difference among devices (Chi-square=24.48, $p < 0.01/2$), adjusted for ties. Given that Chi-square for devices was significant, a multiple comparison product was used to determine differences between devices (see Table 7).

Table 7. Friedman Multiple Comparisons — Subjective Measures

DEVICE	Full keypad (38)	Telepad (16.5)	Dual knob (17)	Single knob (26.5)	Rocker switch (25)	ICAO table (45)
Full keypad (43)	----- -	21.5	21	11.5	13	7
Telepad (22.5)		----- -	0.5	10	8.5	28.5**
Dual knob (16)			----- --	9.5	8	28**
Single knob (26.5)				----- --	1.5	18.5
Rocker switch (20)					----- -	20
ICAO table (40)						-----

** $p < 0.01/2$

Based on the multiple comparisons, there were significant differences between the telepad and the ICAO table, and the dual knob and the ICAO table. The ICAO table was preferred in both cases.

3.2 Performance Results

Thirteen performance indices were used. Of the 13, 5 measures were significantly correlated (Spearman Rank Order Correlation, $p < 0.05$) with perceived difficulty (best representative of the subjective data) for the majority of the participants. These 5 indices are: 1) key count (13 out of 13) with correlations ranging from $-.33$ to $-.65$; 2) maximum tracking error (10/13, $-.39$ to $-.58$); 3) RMS tracking error during trials (8/13, $-.35$ to $-.60$); 4) RMS tracking error after first input (7/13, $-.34$ to $-.55$); and 5) total time to enter data (13/13, $-.37$ to $-.74$). The rest of the objective indices only correlated with perceived difficulty for 5 or less of the subjects and, therefore, were not used. Table 8 shows the mean values for each of the 5 remaining measures per device. The higher the value, the lower the performance.

Table 8. Mean Values for Devices—Objective Measures					
DEVICE	Key count	Maximum tracking error	RMS tracking error during trials	RMS tracking error after first input	Total time to enter data
Full keypad	7.69	0.31	0.15	0.16	14.76
Telepad	19.12	0.63	0.34	0.33	30.99
Dual knob	43.06	0.52	0.23	0.24	37.21
Single knob	13.97	0.47	0.22	0.24	23.88
Rocker switch	33.29	0.43	0.20	0.20	29.13
ICAO table	23.57	0.37	0.17	0.18	21.13

Overall, subjects performed best with the alphanumeric keypad on all 5 performance measures. The ICAO table was second best in all measures except key count. For a clearer picture of the standings for the devices, as well as enabling a ready comparison with the subjective results, the average rankings for the devices on each of the objective measures were calculated (see Table 9).

Table 9. Average Ranks for Devices — Objective Measures						
DEVICE	Key count	Maximum tracking error	RMS tracking error during trials	RMS tracking error after first input	Total time to enter data	Overall Mean Rank by Device
Full keypad	1	1.85	1.85	1.92	1	1.52
Telepad	3.08	4.69	4.92	4.62	4.62	4.39
Dual knob	6	4.88	4.38	4.58	5.62	5.09
Single knob	2.08	4.12	4.38	4.62	2.92	3.62
Rocker switch	4.92	3.15	3.31	2.88	4.62	3.78
ICAO table	3.92	2.31	2.15	2.38	2.23	2.60

The average rankings on the objective measures reflected the same relationship among the devices as did the subjective measures. However, in the present case a rank of 1 was considered best while for the subjective case the rank of six was best. The full keypad was ranked the best followed by the ICAO table. The dual knob was ranked as the worst.

As with the subjective rankings, a Friedman analysis was completed for the data in Table 10. The Chi-square as adjusted for ties was significant ($p < 0.01/2$) indicating an effect due to device for the five objective measures. Given the significant Chi-square for device, the multiple comparison procedure was applied (see Table 10). As in the case with the subjective measures, performance was worse for both the telepad and dual knob devices; the ICAO table was significantly ($p < 0.01$) better in the subjective case, and the full keypad better in the present case. Tables 11 and 12 show, in summarized format, the rankings by device for the subjective and objective data. The tables provide the mean ranks compiled across subjects for devices and data types. The rankings are displayed from the best at the top to the worst at the bottom for the subjective and objective measures.

Table 10. Friedman Multiple Comparisons — Objective Measures

DEVICE	Full keypad (5)	Telepad (24)	Dual knob (26.5)	Single knob (19)	Rocker switch (18.5)	ICAO table (12)
Full keypad (5)	----- -	19*	21.5**	14	13.5	7
Telepad (24)		----- -	2.5	5	5.5	12
Dual knob (26.5)			----- -	7.5	8	14.5
Single knob (19)				----- ---	0.5	7
Rocker switch (18.5)					-----	6.5
ICAO table (12)						----- ---

* $p < 0.05_{/2}$ ** $p < 0.01_{/2}$

Table 11. Rankings by Device for Subjective Indices

	Perceived Difficulty	Locate key	Enter alpha data	Enter numerical data	Enter combination	Error probability	Error detection	Error correction
Best	1	6	6	6	1	6	6	6
	6	3	1	1	5	4	1	1
	4	5	4	5	6	1	2	5
to	5	4	3	4	2	2	4	3
	3	1	2	2	4	5	5	4
Worst	2	2	5	3	3	3	3	2

Key: 1=full keypad; 2=telepad; 3=dual knob; 4=single knob; 5=rocker switch; 6=ICAO table

Table 12. Rankings by Device for Objective Indices

	Key-count	Maximum error	RMS during trial	RMS after 1st input	Total time to enter
Best	1	1	1	1	1
	4	6	6	6	6
	2	5	5	5	4
to	6	4	3	3	5
	5	2	4	4	2
Worst	3	3	2	2	3

Key: 1=full keypad; 2=telepad; 3=dual knob; 4=single knob; 5=rocker switch; 6=ICAO table

The full keypad had the lowest perceived difficulty across all subjects, as well as being the easiest device to enter alphanumeric combinations. Also, the full keypad out-performed all the other devices on the

objective measures. The ICAO table was second place in overall performance and the most preferred device in several subjective categories.

Finally, interest was not in data types per se, but in their association with each device. Thus, rankings were accomplished for data type/device combinations. The 6 tables in Appendix E are based on ordering the mean ranks for the subjective and objective indices by device for data type.

As shown in the tables in Appendix E, the full alphanumeric keypad was first place in preference and performance for each of the 6 data types. The telepad was evaluated worst for performance for the 3-Ltr alpha codes. The telepad required the most effort or workload of all the devices to enter a simple code. However, for more complex codes, the disadvantage was lessened; i.e., single knob was worse in performance for 5-Ltr codes and the dual knob configuration had the poorest performance for Lat/Long codes.

3.3 SWORD Results

A one way ANOVA of the SWORD data did not show significant results $F(65,5)=1.97$, $p<0.094$. This suggests that there was no workload effect across the 6 data devices.

4. DISCUSSION

The primary purpose of this study was to determine whether alternative means to a full alphanumeric keypad entry device were viable for situations where "real estate" is scarce. This study looked at 6 entry devices using 6 types of data. Although the devices were all different, it should be noted that numeric entry was accomplished in the same manner (numeric keypad) for all the devices except the dual knob.

The subjective and objective data point to the full keypad being the most preferred, and subjects performed the best on this device. This was the expected result.

In second place for subject preference and performance was the ICAO table. This configuration provided a space savings in a crowded cockpit as it can be implemented on existing multifunction displays (MFDs) or other small CRT displays. As an example, Cockpit 21, the transformation of the T-45A's forward/aft cockpits from analog to multifunction displays, uses MFDs to enter and sequence waypoint navigation information.

Looking at data types across all the entry devices, the subject's preference for and best performance were achieved with the UHF designators, followed in order by 3-Ltr, 4-Ltr, and 5-Ltr alpha codes, lat/long data, and finally the 3-Ltr/5 digit DME codes. Though the outcome was consistent with expectations, interest was chiefly in how each device performed with each type of data. Again, the full keypad did best, whether the operator entered a UHF designator or a DME code.

In terms of consistency between subject's perceived preference for a device vs. device performance, there were a few cases where the ratings were somewhat at odds; i.e., single knob/5-Ltr alpha perceived preference score wasn't supported by a good performance score. In some cases, the subject's perceived ease or difficulty of entering a data type could bias or color the subject's perception of the entry device.

One anomaly was the full keypad's poor ratings on locating a key despite it being the most preferred device and the device with the best performance. This anomaly may be accounted for by the extended search pattern required to find both an alpha and numeric key as opposed to a search solely for a numeric key on most of the other devices. Training and increased device familiarization would be expected to improve key search time.

Another anomaly was noted for the single knob device. It was rated third in perceived ease of use but was among the worst performers on several objective indices. This discrepancy is accounted for in part by the apparent judgment of subjects that cycling through alpha characters appeared relatively simple, yet like the rocker switch device, the actions required to enter an alpha or numeric character led to less than optimal behavior.

5. CONCLUSIONS AND RECOMMENDATIONS

The data conclusively indicates that the full alphanumeric keypad is best, but if space is a limitation, the ICAO table with a numeric keypad is acceptable. The dual knob and telephone keypad devices should be avoided.

Future keyboard entry studies should simplify the actions required for data entry with the telephone keypad. The design tested in this study required too many keystrokes per single alpha character and thus, was too tedious and time consuming. A simpler implementation should be investigated.

6. BIBLIOGRAPHY

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APPENDIX A

DATA ENTRY PROCEDURES

1. Full Alphanumeric Keypad - Pressing a button will cause that character to appear in the scratchpad. Final acceptance of the entry is made by pressing the appropriate Line Select Key (LSK).
2. "Telephone" Keypad - Pressing a numeric button will cause that number to appear in the LSK field. To enter an alpha character, press the "USE LTR" key, which causes an asterisk (*) to appear in the LSK field, indicating that an alpha character is expected. Press the appropriate key repeatedly until the desired letter is displayed (for the string ABC, press the key two times for "B" or three times for "C"), then press the "USE LTR" key again to complete the character entry. If another alpha character is required, repeat the procedure again. When all characters for the string are entered, press the Line Select Key.
3. Dual Knob Control - This control panel consists of two knobs, one for alpha character entry and one for numeric character entry, and a Clear button. Rotating the "Alpha" knob one click to the right placed an "A" in the LSK field while rotating the "Numeric" knob one click to the right placed a "1" in the LSK field. Turning the appropriate knob one click left placed a "Z" or "0" in the LSK field. Continuing to turn either knob right or left increased or decreased, as appropriate, the value of the character in the field. Pressing in on the knob "Locked-in" the character in the field and moved the "cursor" position one character to the left. Subjects repeated the procedure for additional characters. When all characters for the string were entered, press the LSK.
4. Single Knob Control - This control panel consisted of one knob for alpha waypoint (alpha identifier) entry and a numeric keypad. Turning the knob one click right placed the first waypoint from the systems database (alphabetically) in the LSK field. Continuing to turn the knob to the right or left increased or decreased, as appropriate, the waypoint in the field. Numeric characters were entered by pressing the appropriate button on the keypad. Alphabetic identifiers were treated as single characters when using the "Clear" key; pressing the "Clear" deleted the entire alpha identifier.
5. Increment/Decrement Button Control - This control panel consists of a rocker switch and a numeric keypad. Data entry works on the same principle as system number 3, except that the knob is replaced with a rocker switch which has positions of "increase" and "decrease". Pressing the rocker switch up cycles the characters forward; i.e. starting with "A". Pressing the rocker switch down cycles the characters backwards; i.e., starts with "Z". The numeric keypad was used to enter numeric characters.
6. ICAO Database Table - All the alpha codes were presented in a table format. There were 210 entries with 15 codes per page and 14 pages in all. An up arrow and a down arrow were used to move through the pages. Once on the proper page, two LSKs provided a right arrow and a down arrow to move to the appropriate code. Another LSK was used to finalize the entry. The numeric keypad was used to make numeric character entries and N, S, E and W characters were respectively placed on the 2, 8, 4 and 6 buttons for use when entering Lat/Long data.

APPENDIX B

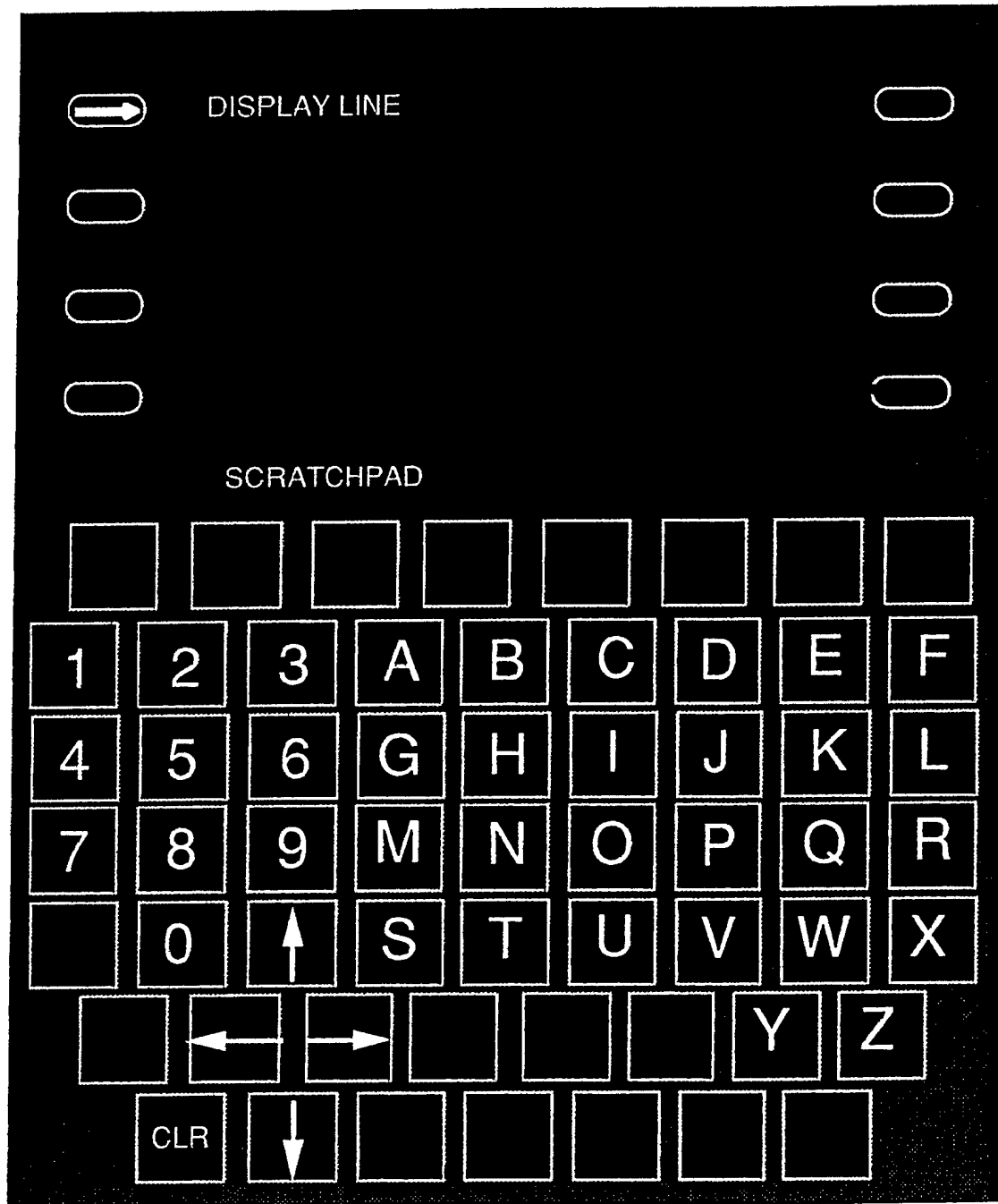


Figure 1. Full Alphanumeric Keypad

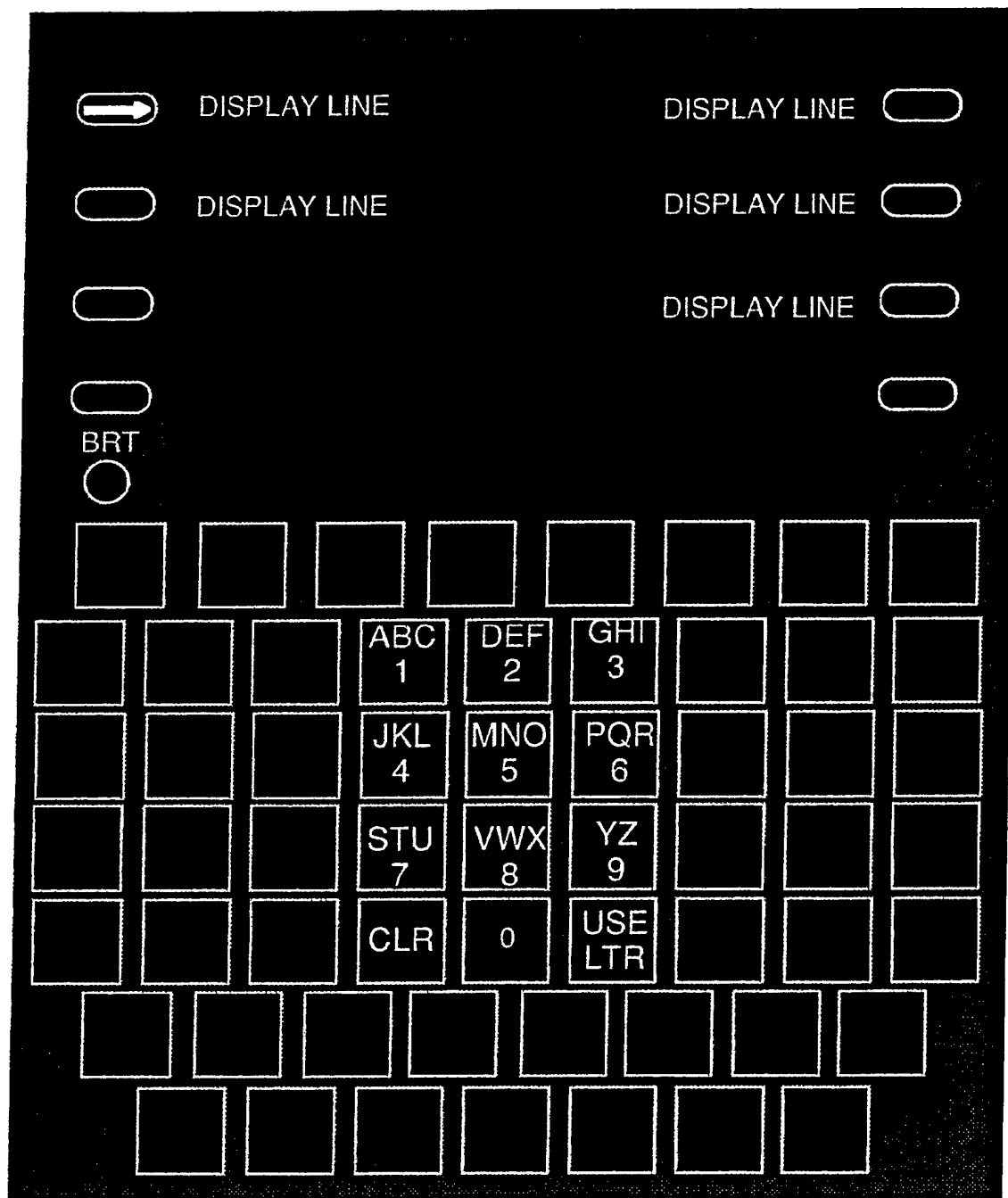


Figure 2. Telephone Keypad

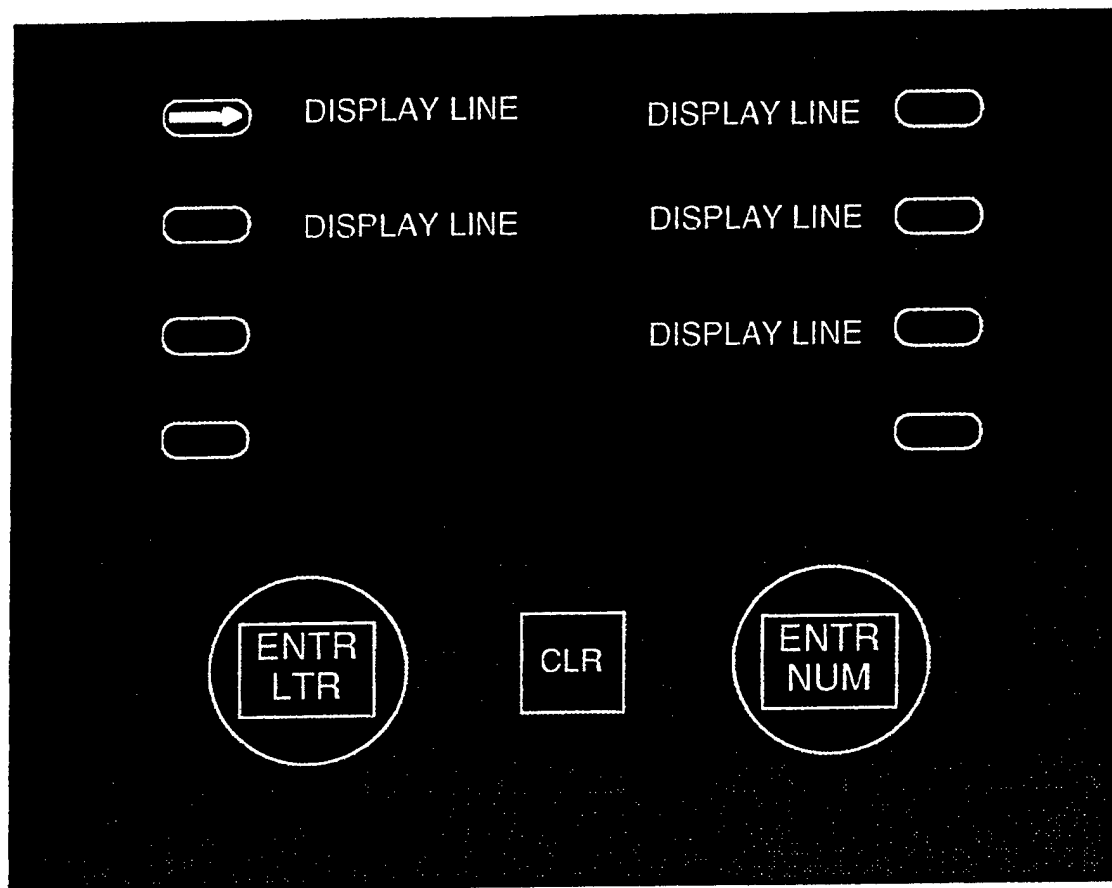


Figure 3. Single Knob and Rocker Switch

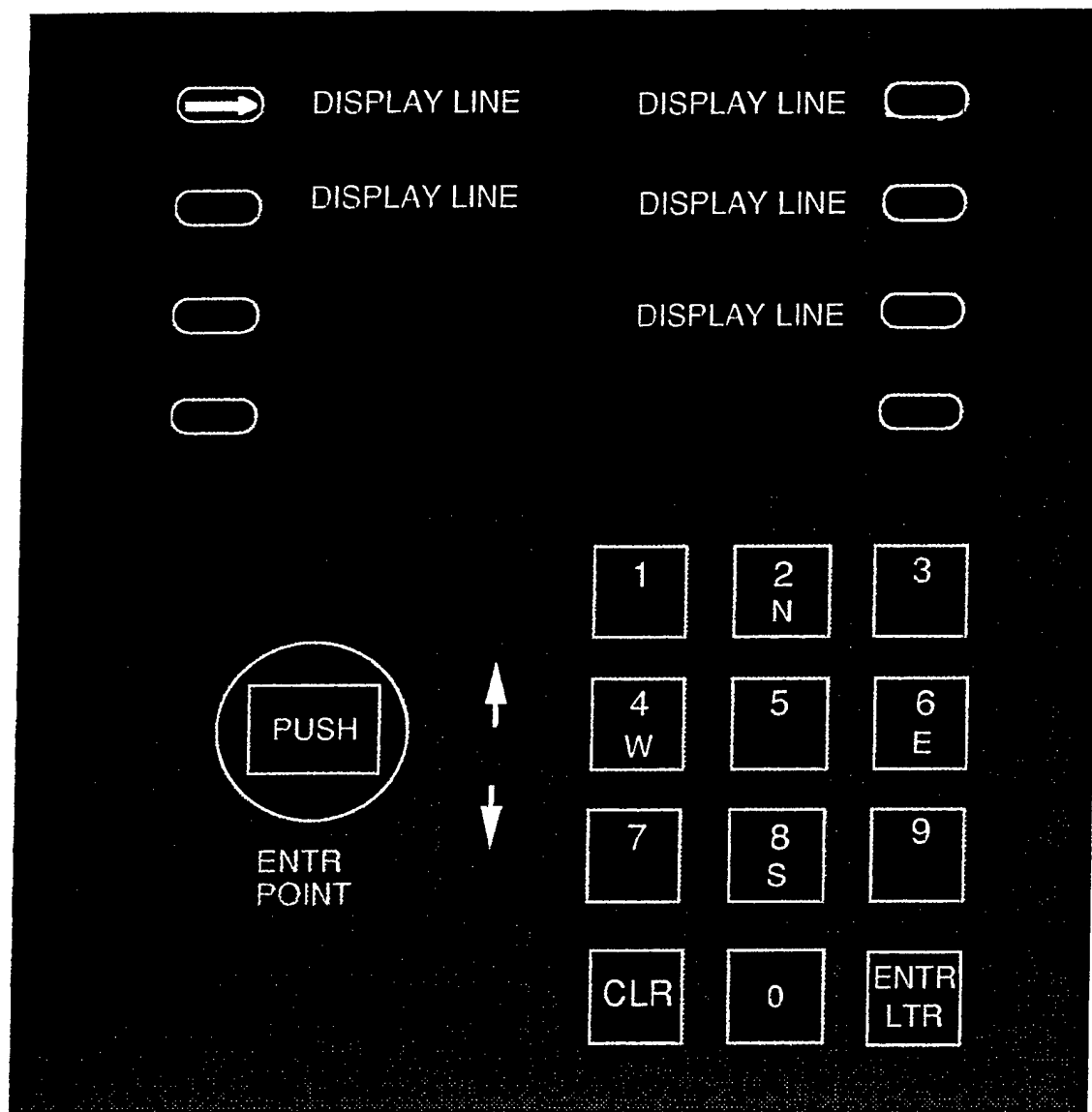


Figure 4. Dual Knob
DATA DEVICES







	ABC	MABD	STA					
	FOZZY	MATW	TATA					
	FRATA	MICK	TERR					
	FRTT	MRI	TROVA					
	GOAT	NANE	UNA					
	>							
	<							
		SELECT 						
								
1	2	3	A	B	C	D	E	F
4	5	6	G	H	I	J	K	L
7	8	9	M	N	O	P	Q	R
	0		S	T	U	V	W	X
						Y	Z	
CLR								

Figure 5. ICAO Database Table

APPENDIX C

DATA ENTRY STUDY SWORD RATING SHEET DATA ENTRY DEVICES

Subject # _____

	Very					Very				
	Absolute	Strong	Strong	Weak	Equal	Weak	Strong	Strong	Weak	Absolute
Full Keypad										Tele Keypad
Full Keypad										Single knob
Full Keypad										Dual knob
Full Keypad										Rocker
Full Keypad										Table
Tele Keypad										Single knob
Tele Keypad										Dual knob
Tele Keypad										Rocker
Tele Keypad										Table
Single knob										Dual knob
Single knob										Rocker
Single knob										Table
Dual knob										Rocker
Dual knob										Table

APPENDIX D
DATA ENTRY STUDY
COMPILED QUESTIONNAIRE DATA

**INDICATE YOUR PREFERENCE WITH AN X FOR THE SCRATCHPAD DATA
 FORMAT VS. THE FIELD DATA FORMAT.**

	SUBJECT NUMBER	TOTAL
Preferred Scratchpad Format	3, 5, 8, 11, 13	5
Preferred Field Format	2, 6, 7, 9, 10, 14	6
No Preference	4, 12	2

Did you encounter any problems due to the data device design that interfered with your ability to enter the data? If yes, please elaborate.

DATA DEVICE	YES (SUBJ No.)	TOTAL	NO (SUBJ No.)	TOTAL
FULL ALPHANUMERIC KEY PAD	2, 3, 10, 13, 14	5	4, 5, 6, 7, 8, 9, 11, 12	8
TELEPHONE KEYPAD	3, 5, 10, 11, 14	5	2, 4, 6, 7, 8, 9, 12, 13	8
ALPHA/KNOB	6, 14	2	2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13	11
DUAL KNOB	2, 3, 8, 14	4	4, 5, 6, 7, 9, 10, 11, 12, 13	9
ROCKER SWITCH	6	1	2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14	12
ICAO TABLE	3, 10, 14	3	2, 4, 5, 6, 7, 8, 9, 11, 12, 13	10

Comments:

S2:

Full alphanumeric keypad was awkward to use because of its position, and how you have to reach. Also, it takes longer to locate (and is more distracting) the proper letter.

Dual knob, especially the right hand knob (since I am right handed and must use my left hand) is more of a reach, and more tiring to use.

S3:

Full alphanumeric - hard to locate proper key. Full [alphanumeric] pad was easiest but I was tired and bored by this point.

Telephone keypad - not good for letters; but good for numbers.

Alpha knob - tiring and annoying.

Dual knob - tiring and annoying.

ICAO Table - hard to see icons [alpha string] for table; table would be good if easier to use like a ball mouse or something instead of keys.

S5:

Having to press the "use ltr" key twice (once to enter and once more to prepare next position) is a bad method for data entry. Easier methods exist (even in smaller civilian airplanes).

S6:

Minor, numeric keys had worse feel than other devices.

S8:

Only device [dual knobs] where I felt physical strain on hands (actually wrist area) while entering data. Doing Lat/Long with dual knobs was very tedious.

S10:

Alphanumeric - scratchpad was hard to read and distinguish sequence of letters; it all ran together.

Telephone - minor, the "YZ" was in the second/third position on key but entry on 1st/2nd depression.

ICAO Table - It would be helpful to go both directions on the sub menu.

S11:

After making last entry [Telephone Keypad] having to press for acceptance before pressing line select key.

S14:

Full alphanumeric - hard to find letters.

Telephone keypad - keypad too small, buttons too small.

Alpha knob - too much attention is needed to find numbers/letters.

Dual knob - too much attention is needed to find numbers/letters.

ICAO Table - Hard to find value on table; switch operation a bit complex.

Do you have any suggestions or comments that you would like to make?

S2: You may wish to use different test sheets, because after a few "rounds" you start getting familiar with some of the codes.

S3: I like the keypad but it needs to be more reachable and the buttons could be easier to activate.

S4: Make the test different for each format, because that affected my ability to enter data better (I had it memorized). Randomization of testing order between subjects would accomplish same.

S6: I liked the alpha knob better than the table, and almost as well as the full keypad, but if there were more data in the table, the full keypad would easily be the best. If there were less data, the alpha knob would be better than the full keypad.

S8: There is a huge difference between the 2 display monitors. This makes error recognition much easier on this display.

Although the knobs make cycling fast, I'd be wary of how much wear and tear these knobs will undergo as users attempt to spin them quickly. From a Logistics/Maintenance standpoint, does the increased efficiency justify what the failure rate for these knobs will be?

S13: Full keypad and phone keypad are more commonly used. Table was also a short cut as was alpha knob.

APPENDIX E **MEAN ORDER RANKS FOR DATA TYPE**

Table 13. 3-Ltr Alpha

3-Ltr Alpha							
Subjective			Objective				
	Difficulty		Key count	Max Error	RMS during	RMS after	Total Time
Best	1	Most	5	2	2	2	2
	6		6	5	5	5	5
	5		3	4	4	4	4
to	4	to	2	3	3	3	3
	3		4	6	6	6	6
Worst	2	Least	1	1	1	1	1

Key: 1=full keypad; 2=telepad; 3=dual knob; 4=single knob; 5=rocker switch; 6=ICAO table

Table 14. 4-Ltr Alpha

4-Ltr Alpha							
Subjective			Objective				
	Difficulty		Key count	Max Error	RMS during	RMS after	Total Time
Best	1	Most	5	4	4	4	5
	6		6	2	2	3	2
	4		3	3	3	2	3
to	3	to	2	6	5	6	6
	5		4	5	6	5	4
Worst	2	Least	1	1	1	1	1

Key: 1=full keypad; 2=telepad; 3=dual knob; 4=single knob; 5=rocker switch; 6=ICAO table

Table 15. 5-Ltr Alpha

5-Ltr Alpha							
Subjective			Objective				
	Difficulty		Key count	Max Error	RMS during	RMS after	Total Time
Best	1	Most	5	4	4	4	5
	6		3	2	2	2	2
	4		*2	5	5	5	3
to	5	to	*6	3	3	3	4
	2		4	6	6	6	6
Worst	3	Least	1	1	1	1	1

Key: 1=full keypad; 2=telepad; 3=dual knob; 4=single knob; 5=rocker switch; 6=ICAO table

Table 16. 3 Ltr-Alpha/5 Digit DME

3-Ltr Alpha + 5 digit DME							
	Difficulty		Key count	Max Error	RMS during	RMS after	Total Time
Best	1	Most	3	2	2	3	3
	6		5	3	4	2	2
	4		6	4	3	4	5
to	2	to	2	6	6	6	4
	5		4	5	5	1	6
Worst	3	Least	1	1	1	5	1

Key: 1=full keypad; 2=telepad; 3=dual knob; 4=single knob; 5=rocker switch; 6=ICAO table

Table 17. Longitude and Latitude

Longitude and Latitude							
	Difficulty		Key count	Max Error	RMS during	RMS after	Total Time
Best	1	Most	3	3	3	3	3
	6		5	2	2	2	2
	4		2	4	4	4	5
to	5	to	6	6	6	6	4
	3		4	5	5	5	6
Worst	2	Least	1	1	1	1	1

Key: 1=full keypad; 2=telepad; 3=dual knob; 4=single knob; 5=rocker switch; 6=ICAO table

Table 18. UHF Designators

UHF Designators**							
	Difficulty		Key count	Max Error	RMS during	RMS after	Total Time
Best	1	Most	3	3	3	3	3
	6		5	2	2	2	2
	5		2	4	4	4	5
to	2	to	6	5	5	6	4
	4		4	6	6	5	6
Worst	3	Least	1	1	1	1	1

** With the exception of dual knob, all UHF data are inputted in the same manner

Key: 1=full keypad; 2=telepad; 3=dual knob; 4=single knob; 5=rocker switch; 6=ICAO table